Aruba has a population of approximately 92,000 people and its main source of business is tourism and oil refining. Aruba has experienced a great deal of growth over the past decade which is stressing the capabilities of the water system. Potable water is supplied throughout the island from a single water desalination and treatment plant and distribution system operated by Water-En Energiebedrijf Aruba N.V (WEB). Currently Aruba is planning for future development and as a result the water distribution system must expand to meet the water needs for drinking, fire protection, and commercial and industrial uses.

WEB faces a unique set of challenges in planning for the long term needs in the distribution of water. These challenges include rapid external pipe corrosion caused by the island soils, internal pipe corrosion associated with distilled water, inadequate system storage volumes and aged or undersized water mains. Each of these challenges were addressed in the development of the Master Plan and the resulting document provides the framework for implementing a series of strategic improvements that will correct existing deficiencies and provide for the long term needs of WEB. The recommended improvements include over 165,000 meters of new pipelines, 6,600 cubic meters of additional storage, a new pumping station and a variety of miscellaneous system improvements intended to be implemented over a ten year period. Total estimated project cost is 57,000,000 Af.

Key Words, water, planning, distribution, corrosion, desalination

O’Brien & Gere was retained by WEB to study and assess the current conditions of their water distribution system and provide direction for expanding and improving the system to provide adequate service to the Island of Aruba. This presentation will provide a summary of the existing system conditions that led to the study and the recommendations that have been made for expanding and improving the distribution system.

Recommendations for expanding the system are be based on a preliminary hydraulic model of the distribution system. The model has been developed to a condition that allows a broad overview of the system such that planning-level recommendations and estimates can be made. Included in the recommendations are the following:

- Transmission/Distribution Pipelines
- Water Storage Facilities
- Pumping Facilities
- Operation and Maintenance Procedures
- Instrumentation and Control
Background

Aruba has experienced a great deal of growth over the past decade which is stressing the capabilities of the water system. During the late eighties the Aruban economy grew at a high rate and with it increased demand on WEB's aging distribution system. As a result several pumping stations were added to boost pressure and a storage tank was added.

Development in the early nineties has also been high but is expected to slow down significantly in the next five years. With the pumping and storage tank projects in operation it is now apparent that the pipe infrastructure is in need of rehabilitation and expansion to meet current and future demands. Currently Aruba is planning for future development and as a result the water distribution system must expand to meet the water needs for drinking, fire protection, and commercial and industrial uses.

The Island consists of two major metropolitan areas; Oranjestad and San Nicolas. The terrain on the Island varies from being flat and low along the western and south western coast line to hilly along the northern coast and in a central region north of San Nicolas. The ground surface ascends from sea level along the coast to a highest elevation of 188 meters at Jamanota, which is in the center of the southern half of Aruba.

The water treatment plant is centrally located along the southern coast of Aruba in Balashi. WEB pumps water from the sea and treats it to produce a high quality drinking water for distribution at its Balashi Plant. The treatment process includes low lift pumps to convey sea water to multi stage flash evaporation units, which desalinates the water. After desalination the water is pumped through two separate treatment processes; one for water that is supplied to Aruba and the other for industrial water. Aruba water is treated by filtering through a coral bed for calcium addition and then pumped through anthracite filters to remove fine particles. Pyrophosphate is added before filtering and zinc sulphate is added as a corrosion inhibitor before pumping finished water into the distribution system.

The distribution system is made up of a network of pipes, tanks, pressure regulating valves and pumping stations. There is approximately 733 km of pipes ranging from ½ inch to 16 inch. The pipes vary in age from 0 to 55 years and the majority of the pipes are made of cast/ductile iron with some galvanized and copper lines. The total water distribution storage volume is 76,550 m³ which is distributed around Aruba among 7 reservoirs and 2 elevated storage tanks. Each tank provides storage volume for its own pressure zone.

The water system is fed by two sets of high lift pumps located at the Balashi Plant. One set pumps industrial water directly to the Coastal Refinery and the other pumps "Aruba-water" to the distribution system. Water is pumped from the Aruba-water pumps to a common header which branches out to feed the distribution system. Pressure in the header is maintained at approximately 12 bars and branches out to four outlet lines, each with a pressure regulating valve that maintains a discharge pressure of approximately 7.5 bars or a gradient of 81 M.

Currently there are ten pressure zones and each one has its own storage tank. Generally the high lift pumps feed into the Mondi Fierno pressure zone and then booster pumping stations feed water into the other pressure zones. The exceptions to this are the San Nicolas and Oranjestad zones which are at a lower pressure gradient than the Mondi Fierno zone. The flow of water into these zones is regulated by altitude valves on the inlet lines to the water towers. One other exception is the Seroe Colorado area which is fed industrial water through the Coastal Oil Refinery. This system includes a storage tank and
pumping on the refinery property.

The booster stations are distributed around Aruba and generally in the area of the pressure zone they are serving. The pumps in these stations are all manually operated. Operation of the pumps is based on tank levels in the corresponding pressure zone.

Walk through inspections were conducted at each facility to document physical components and system operation and maintenance. The inspection program included pumping stations, storage tanks, major valve stations, and pressure regulating valves. The facility inspections and associated evaluations that followed identified a number of areas for improvement including:

- Low static pressures
- Low pressures during peak demand periods
- Improperly sized pumping equipment
- Severely corroded pipe
- Numerous dead end pipelines
- Inefficient pressure district boundaries
- Isolated areas of inadequate storage
- Lack of a consistent management and design strategy
- Insufficient points for measuring flow/pressure

**Insufficient measuring points for flow/consumption**

The essence of this problem is accountability of water use and the cost of production. Current estimates indicate the WEB can account for all but about 8.2% of the water produced. While this level of accountability is very good by industry standards the production cost savings or lost revenue is significant. Based on current production rates of about 29,000 M$^3$/day and a retail sale price of 5.15 Af/M$^3$, the total potential revenue loss is almost 4,500,000 Af per year. Consequently, improving accountability by just one percent has a major financial impact.

**Storage**

A storage capacity analysis was performed to evaluate the sufficiency of WEB's storage volume. Generally, with a total storage volume of about 73,350 m$^3$ it appears that WEB has sufficient storage since this represents roughly more than 2½ days of water usage. However, there are ten separate pressure zones with storage capability in each. Furthermore, each pressure zone is at a different gradient and sharing of storage volume between some pressure zones would require significant improvements. To evaluate the storage capacity each pressure zone was considered separately to see if it can provide sufficient storage for the customers in that area. Since WEB has no established guidelines for its storage requirements general rule-of-thumb values were utilized for this analysis.

There are three components to consider when evaluating distribution system storage requirements; these components are equalization, fire flow, and emergency storage volumes. Equalization storage is the volume between the normal high operating level and the normal low operating level. Equalization storage volume is used when system demands are in excess of the delivery capability (i.e., pumping capacity). This allows the tanks to drain during daily peak demands and fill at off-peak times. In this analysis the equalization volume was estimated at 25% of the average daily demand (10% of current total storage volume).
Fire flow storage is usually established based on the characteristics of the individual buildings in the service area. When the characteristics have been established a fire-stream duration is selected that will adequately suppress a fire in that area. A comprehensive survey of each service area would have to be conducted to establish the most accurate requirements. For the purposes of this analysis a reasonable fire-stream duration of 158 l/s for 2 hours was used. For emergency situations such as pipeline failures, major transmission main failures, equipment failures, electrical power outages, water treatment plant failures, or natural disasters emergency volume must be provided. The volume of such emergency capacity is generally established by the owner based on an assessment of risk and desired degree of system dependability. This analysis used an emergency volume equal to the average daily demand of the service area.

The results indicate that there is sufficient capacity with the exception of Oranjestad and San Nicolas service areas. Generally these are high demand areas with small storage tanks. It should also be noted that in the Harbor area the tank is at ground level and the water is boosted to that area through the Harbor Pumping Station. In the event of a electrical power failure the water in the tank can not be delivered to the service area.

To increase system reliability it is recommended that these deficiencies be corrected. In Oranjestad the analysis indicates that an additional 3,246 m$^3$ of storage is necessary to serve this area and recommendations were made to increase storage in this area to a total of about 3,600 m$^3$.

In San Nicolas, there is a storage deficiency of roughly 2,600 m$^3$. It is recommended that the storage in this area be expanded from 375 m$^3$ to about 3,000 m$^3$. Also, it is recommended that either emergency power be installed at the Harbor Pumping Station or provide interconnections with the Alto Vista service area. This will allow surplus storage to be used under emergency conditions. This can be accomplished by locating pressure reducing valves on interconnections such that when the pressure in the Harbor area drops to a preset pressure the valves open and water is allowed to pass into that area.

**Corrosion**

A corrosion investigation was conducted to understand the nature of the corrosion problems WEB has been experiencing. The program included a review of current corrosion control practices and collection of information relative to current problems. Corrosion effects both the interior and exterior of pipes. Interior corrosion is dependent upon water quality and pipe materials, while exterior corrosion is dependent upon soil conditions and pipe materials.

Internal corrosion can have a significant impact on a water distribution system. Symptoms of internal corrosion include increased pumping costs; loss of water and water pressure, caused by leaks; water damage to surrounding facilities; and water quality problems that result in customer complaints of colored water, poor taste and staining.

External corrosion can also have a significant impact on the distribution system. Corrosion of this nature can impose major cost implications to a utility for replacing corroded pipes. In addition, leaks can occur causing loss of water and water pressure.

Presently, WEB has a corrosion control and monitoring program for interior corrosion. The corrosion control program includes maintaining a consistent water quality and utilizing chemical addition for inhibiting corrosion. Aruba Water is filtered through a coral bed and receives a treatment of
pyrophosphate and zinc sulphate to inhibit corrosion. Caustic soda and hexametaphosphate are added to the Industrial Water to control pH and inhibit corrosion.

The current internal corrosion control program has significantly reduced internal corrosion rates. The buffering capacity of Aruba water is still low and the program is not totally successful, however. When new cement lined ductile iron pipe is installed the pH of the water near the new main increases to approximately 11 for a period of approximately two years. The pH then drops to the more typical pH found throughout the distribution system of between 9.0-9.5.

The Ductile Iron Pipe Research Institute was consulted and research articles from the AWWA were reviewed to find out if cement lining on the pipe is being damaged over time. Based on that review, no cases of excessive leaching or failure of the cement lining were identified, however significant softening of the cement lining has been documented in similar low alkalinity supplies. In order to minimize this softening, stabilize distribution system water quality and safeguard against potential failure of the lining the following actions are recommended:

- Specify a seal coat, applied to the cement lining at the time of manufacturing, to strengthen the cement lining and retard the leaching rate.
- Specify a double thickness cement lining. Many pipe manufacturer’s standard product has a double thickness to address customer concerns. Consequently, there is very little if any cost difference between single and double thick lining and the double lining will last longer.
- Investigate treatment techniques to improve buffering capacity of the Aruba water.

The current internal corrosion monitoring program includes water sampling throughout Aruba and corrosion measurement through a coupon weight-loss method. This information is valuable in maintaining water quality and quantifying corrosion rates. Prior to 1995 the typical corrosion rate was approximately 6.2 mils per year (MPY). Since 1995 the corrosion rate has been reduced to 2.8 MPY. This information has been used to develop a pipe replacement program for rehabilitating the distribution system piping. The program provides an estimated remaining useful life of unlined iron pipe. Actual replacement schedules should be adjusted based on leakage and line break history for each particular main. The Estimated Replacement schedule is as follows:

<table>
<thead>
<tr>
<th>Current pipe age</th>
<th>Estimated wall loss to date (Mils)</th>
<th>Percent of wall corroded*</th>
<th>Estimated remaining useful life**</th>
</tr>
</thead>
<tbody>
<tr>
<td>30+ years</td>
<td>179</td>
<td>72%</td>
<td>less than 5 years</td>
</tr>
<tr>
<td>20 years</td>
<td>117</td>
<td>47%</td>
<td>25 years</td>
</tr>
<tr>
<td>10 years</td>
<td>55</td>
<td>22%</td>
<td>50 years</td>
</tr>
</tbody>
</table>

*based on an estimated wall thickness of 0.25 inches.
**Useful life based on corrosion of 75% of original wall thickness.
The corrosion rate has significantly dropped over the last four years. Therefore, pipes installed over the last 5 years have not been exposed to a highly corrosive water and are cement lined. Consequently, the life of these pipes will be much greater.

External corrosion has not been as closely monitored as internal corrosion, however external corrosion is a problem in many areas of the distribution system. The electrolyte in external corrosion is the surrounding soil. The make up of the soil conditions influences the corrosion process. Potentially corrosive conditions include:

- different metals or alloys in contact with each other and with a common media, such as water or soil, that may be conducive to corrosion;
- great variances in soil in contact with metal or alloys;
- contamination of soil with refuse, cinders, coal mine waste, or salts;
- naturally occurring corrosive soil;
- chemical contamination of soil may deteriorate pipe, valve and fitting materials.

When these conditions are present, preventive measures should be taken to minimize deterioration due to corrosion.

To understand the nature of corrosion on the exterior of the system piping a study was conducted as part of the Master Plan. The study included conducting a sampling and testing program to evaluate the corrosivity of the soil around the pipes.

The sampling and testing program included pipeline excavations at various locations in the system to develop a representative sample of the conditions in Aruba. At each location a pipe was excavated and information about the pipe was recorded, a sample taken and stray-current measurements taken. The stray-current measurements were taken to ascertain whether any direct current is flowing through the soil or pipeline that might induce electrolytic corrosion. Generally ductile iron pipe is not vulnerable to stray-currents due to each pipe segment being electrically insulated by the gasketed joints. However pipe-to-soil potential can cause localized corrosion if the conditions are conducive.

To understand the cause of corrosion in Aruba a common procedure was used to analyze the soil and evaluate the environment to find out if the soil is corrosive to ductile iron. This system is the 10-point soil evaluation procedure which was originally developed by the Cast Iron Pipe Research Association in 1964. The evaluation procedure is based upon information drawn from 5 tests and observations: soil resistivity, pH, oxidation-reduction (redox) potential, sulfides, and moisture. For a given soil sample, each parameter is evaluated and assigned points according to its contribution to corrosivity. The points for all five criteria are totaled. If the sum is 10 or more, the soil is considered corrosive to ductile iron pipe and protection measures should be taken.

The test results indicate that various corrosive situations can exist in a variety of locations in the distribution system. From the results it can be concluded that the nature of the soils are varied. It can also be concluded that there are some situations where stray currents can influence corrosion. Since the conditions at each location are unique in terms of environmental influences it can also be concluded that controlling the external conditions surrounding pipelines would be impossible. Rather, it is more
appropriate to insulate the pipe material from its environment.

Historically, WEB has utilized a number of external corrosion protection techniques with mixed results. These techniques have included tape coatings on pipe barrels and wrapping the pipe with polyethylene. Based on several failures with the polyethylene wrap the preference is toward use of tape coatings. Each system has advantages and drawbacks but proper installation and a system wide approach is critical to the success of either system. When a tape coating system is utilized in corrosive soils it is very important to properly apply the tape coating to the entire buried piping system including the pipe barrel, pipe bell and all fittings, valves and appurtenances. Otherwise a corrosion cell will concentrate at the fittings and premature failure of the fittings will occur.

The use of properly installed polyethylene wrap systems is strongly supported by DIPRA and our experiences have generally been good. A properly installed system significantly reduces the corrosion rate and spreads the corrosion more uniformly across the full perimeter of the piping system. Wrappings may however not perform as well in situations where the soil moisture content varies significantly throughout the year.

**Management objectives**

Management objectives are criteria that is used to develop a policy for water system planning and design. A policy on the level of service to be provided by a water utility should be developed based on criteria such as fire protection, system reliability, storage capacity, system mapping and records. In addition, a set of engineering guidelines provide the framework to achieve the designated objectives.

A comprehensive set of management objectives were developed for this project and future work through extensive discussions with WEB staff and guidance documents developed by the following organizations:

- World Health Organization
- American Water Works Association
- Great Lakes - Upper Mississippi River Board of Public Health and Environmental Managers

The management objectives were utilized in conjunction with the preliminary modeling efforts to evaluate existing problem areas in the distribution system and plan for future growth.

One of the recommended management objectives is that WEB consider fire protection standards in the design of all future improvements and system upgrades. This practice will have minimal cost impact, help distribution system pressures during normal operation, minimize loss of pressure due to internal corrosion/tuberculation of pipes and minimize the cost pumping. Furthermore, the cost of upgrading the distribution system to meet fire demands in the future will be less. Upgrades to existing facilities to provide fire protection does not appear appropriate until a financing program is developed.

To maintain a high level of reliability it is recommended that each pressure zone incorporate one of the following systems:

- storage tank with a capacity suitable for equalization, emergency and fire volumes
- hydropneumatic tanks in areas serving less than 30 homes
• pressure reducing valves to allow flow into pressure zone from a higher pressure zone
• emergency power in pressure zones that rely on pump operation to maintain pressure.

It is recommended that WEB establish engineering guidelines to ensure an adequate level of service commensurate with service policies. Engineering guidelines should be established so that WEB’s engineers and consultants use these standards to design acceptable systems.

Hydraulic modeling

In developing the master plan for the water distribution system one of the principal objectives was to analyze the hydraulic adequacy of the existing system. The analysis was conducted using a hydraulic computer model. The model was developed from information gathered in the field reconnaissance portion of this project.

The model is a representation of the distribution system which simulates its hydraulic conditions. It was used as a basis for recommending distribution system improvements for both short and long term planning. The model for this project was set up using information provided by WEB, which included mapping, pump data, tank data, pipe data, valve data and operations information. Since field testing of the system was not included in this portion of the project rule-of-thumb values were used where empirical data was not collected. As a result calibration of the model was not possible. However, the model was sufficiently developed to provide information suitable for planning purposes.

Through the field reconnaissance portion of this project it was learned that the network of pipes is old and deteriorating. With the large growth that occurred in the eighties and nineties the system has been pushed near its limit. As a result WEB has been experiencing many problems related to pressure and pipe failures which has imposed a burden on its maintenance staff. The modeling results confirmed and quantified these observations. Utilizing the management objectives and recommended design guidelines established each of the identified problem areas was then systematically evaluated. The result was a comprehensive set of pipeline, pumping and storage system improvements which collectively position WEB to meet the projected needs of the distribution system well into the future.

Recommendations

As a result of this study many distribution system recommendations have been made. These recommendations are necessary to provide a level of service desired by WEB and improve system reliability while minimizing operating expenses. A summary of the recommendations are outlined below. The total estimated project cost including design and a contingency allowance is 57,000,000 Af. These improvements have been scheduled for implementation over a ten year period.

Recommended System Improvements

• Approximately 108,000 meters of water main replacement
• Approximately 58,000 meters of new transmission main
• Pumping and storage Upgrades in the Golf Weg/Juana Morto area
• New 3600 m³ Tank in the Primavera/ Plantersrust
• Installation of distribution pressure monitoring stations
• 450 Fire hydrants
• Tank level telemetry system